Ku-band Channel Signal Generator Based on a Statistical Channel Model

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Abstract

Some wireless channel models based on probability density functions have been proposed, including models based on Markov chains. However, they are limited to a certain number of perturbations. This paper proposes a methodology based in a Ku-band signal behavior which is classified in three cases: ascendant, descendent and constant. Samples are classified in these cases so their conditional probabilities are analyzed in order to find a fit to a probability density function and to extract its statistical parameters which are the model itself. From this information, a new signal was generated and their second order statistics are compared with the ones from the original signal to validate the created model. The analyzed signal was extracted from a measurement campaign done in Mexico.

Keywords

Ku Band Channel Model; Statistical Channel Model; Signal Generator; Second Order Statistics

Introduction

A deep knowledge is required in the design and optimization of wireless communication systems. Models based on probability density functions (pdf) are not enough to characterize a dynamic channel because they only describe one type of phenomenon so other alternatives are analyzed. Many publications describe models created from measured samples where the signal is analyzed as a random variable and only one perturbation is characterized or it can only be applied to certain frequency or system. Other models are based in Markov chains which implies the combination of many phenomena however they are limited to a pre-established number of states or events during the transmission [(Barts, 1988), (Fontan, 2001), (Abouraddy, 2000), (Kattenbach, 2002), (Eberlein, 2007)].

Another alternative for channel modeling is to analyze the variations in the level of the signal due to all phenomena (like rain, scintillation, etc.) which produces its fading. These variations are denominated as the dynamic of the wireless signal. The classification according to this dynamic is suggested by U.C. Fiebig in (Fiebig, U.-C, 1999) where samples which contain the attenuation of a signal are classified in three cases: ascending, descending and constant. An example of this classification is shown in FIG. 1.

A wireless channel model for a set of samples from a Ku band signal is proposed in this paper. The model is based on works of (Fiebig, 1999) where a classification of the samples is done according to its dynamic, next a goodness of fit test is done to know which pdf fit best. The objective is to extract the statistical parameters of the fitted pdf for every value of level of the signal and case. These data are the model itself and a new time series can be generated from them. The validation of that process is done by comparing the second order statistics (average fading duration –AFD - and level crossing rate - LCR) of the original signal and the new generated signal. The document is organized as follows: the measurement campaign organized to extract the samples of the signal is described in section II; in section III the methodology is explained and it will be applied to data in order to obtain a new signal; results are explained in section IV; conclusions are given in section V.

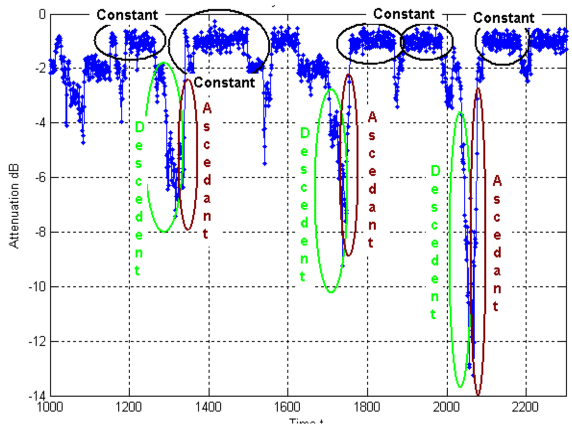

FIG. 1 CLASSIFICATION OF SAMPLES ACCORDING TO ITS DYNAMIC

Measurement Campaign

The signal whose behavior was studied comes from Intelsat 9 satellite which transmits the SKY Mexico's direct-to-home TV service (LyngSat, 2012). The central frequency of the analyzed signal is 12 GHz. The measurement campaign was done from August 25th to November 30th, 2011 at Tecnológico de Monterrey Campus Estado de México. FIG. 2 shows the diagram of the measurement system used.

FIG. 2 MEASUREMENT SYSTEM FOR THE MEASUREMENT CAMPAIGN

Since rain is the principal source of attenuation in Ku band, quantity of rain was used as a base to organize the collected data. This parameter was taken from SEMARNAT data base whose sampling time is 10 min (Secretaría, 2010). According to this information, two periods were identified, one with a higher average of quantity of rain than the other. In this paper, all samples that corresponds to the higher quantity of rain were analyzed which covers from August 25th to October 15th, 2011 with average quantity of rain of 0.0419 mm. The measured signal for this period is shown in FIG. 3 and FIG. 4 shows the samples of quantity of rain; for both FIG.s, 0 min corresponds to the first taken sample for the analyzed period.

In this type of data processing it is recommended to take only that samples that represents all the set of data, reducing in this way the quantity of information and its processing time (Husson, L., 2002). This process was done by using principal component analysis (PCA) which is a non-parametric method where the synthesis of the information is done for the purpose of reveling structures based on the variance and covariance of the analyzed data. The parameter to determine the most important information was based on Velicer algorithm and by using (1).

$$f_k = \sum\sum_{i \neq j} \frac{\left(r_{ij}^k\right)^2}{\left[p\left(p-1\right)\right]} \tag{1}$$

Where,

f_k, Sum of the square of the partial correlations in k.

r_{ij}^k, Correlation matrix R_k.

p,, Number of dimensions of the original set of data.

Methodology

The input data to begin the process are the results obtained after PCA where data are reduced and thus the time of processing too. Then, from the observation of the signal, three cases are identified: increasing or decreasing of it level or maybe stays near the same point. The cases are characterized as it is shown in (2).

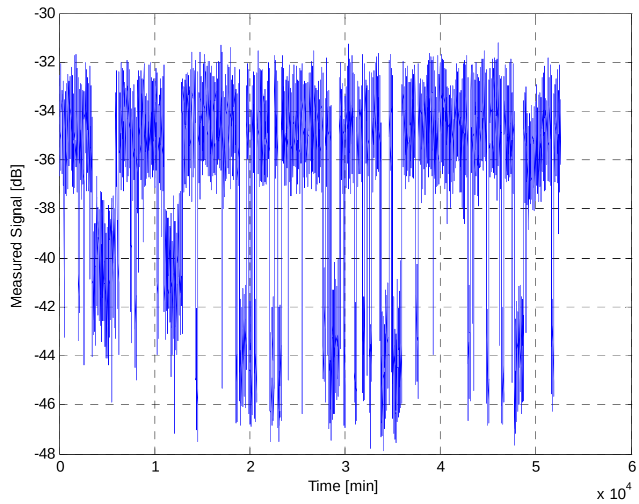

FIG. 3 MEASURED SIGNAL

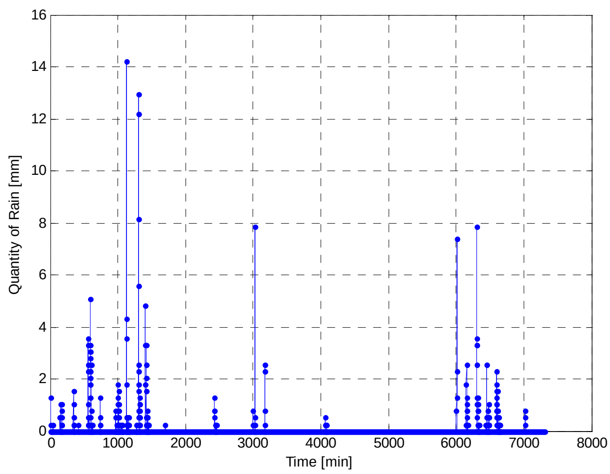

FIG. 4 QUANTITY OF RAIN

$$r_{dynamic} = \begin{cases} r(t) - r(t-1) < 0 & \text{Descendent} \\ r(t) - r(t-1) > 0 & \text{Ascendant} \\ r(t) - r(t-1) = 0 & \text{Constant} \end{cases} \tag{2}$$

Where,

$r_{dynamic}$ Classification of the signal according to

its dynamic.

r(t), Current sample.

r(t-1) Previous sample.

Data are separated in groups according to (2) and each group is analyzed in pairs of samples in order to obtain the conditional probabilities of two consecutive events including the case where the same event appears. The equation for this step is shown in (3).

$$p_{X|Y}\left(r_{dynamic}(t) \mid r_{dynamic}(t-1)\right) = P\left\{X = r_{dynamic}(t) \mid Y = r_{dynamic}(t-1)\right\} = \frac{P\left\{X = r_{dynamic}(t), Y = r_{dynamic}(t-1)\right\}}{P\left\{Y = r_{dynamic}(t-1)\right\}} = \frac{p\left(r_{dynamic}(t), r_{dynamic}(t-1)\right)}{p_Y\left(r_{dynamic}(t-1)\right)} \quad (3)$$

Where,

$r_{dynamic}$, Current sample.

$r_{dynamic}(t-1)$, Previous sample.

This methodology is based on Fiebig's work [6]. Also this process is similar when a Markov chain analysis is done (Diana Alejandra Sánchez-Salas, 2008) but in this case there are not a limited number of states.

A Chi-square goodness of fit test with a confidence interval of 95% is done for each level value and case (ascending, descending and constant). The null hypotheses for each test are in (4) – (7).

First null hypothesis:	H_0: data fits a Normal pdf	(4)
Second null hypothesis:	H_0: data fits a Weibull pdf	(5)
Fourth null hypothesis:	H_0: data fits a Rice pdf	(6)
Fifth null hypothesis:	H_0: data fits a Rayleigh pdf	(7)

The choice of these pdfs is because they are the most common used (Proakis, 2008). Once it is determined the pdf with best fit, three tables containing the statistical values with the pdf, one for each case (ascendant, descendent and constant) and for each possible level value of the signal in dB. Data from these tables are the input parameters for the time series generator. The generated samples are analyzed in pair by following (8).

$$\Delta_{2samples} = n_{t-1} - n_t \quad (8)$$

Where,

$\Delta_{2samples}$, Difference between two samples.

nt-1, First or precedent sample.

nt Second or current sample.

Computed results from (8) are classified into three cases as it is shown in (9).

$$r'_{dynamic} = \begin{cases} \left|\Delta_{2samples}\right| \le 1 & \text{Constant} \\ \Delta_{2samples} > 1 & \text{Descendent} \\ \Delta_{2samples} < 1 & \text{Ascendant} \end{cases} \quad (9)$$

Where,

$r'_{dynamic}$, Classification of the generated signal according to its dynamic.

$\Delta_{2samples}$, Difference between two samples.

These three possibilities are the same as original cases of (2) so it is deduced this is an inverse process. Once the case was identified, a new sample is generated based on the statistical parameter that corresponds to the case and the current level of the signal. The final step is to validate the generated signal is statistically similar to the original signal through second order statistics (Pérez Fontán, 2008).

Results

Ku-band Channel Model

From PCA it was obtained that all samples corresponding to the first eight days contains the most important information and the firsts four days for condition 2. These are the samples that will be analyzed. The results after this classification are shown in FIG. 5.

Next, samples were analyzed in pairs to compute the conditional probabilities of each event. Then, Chi square goodness of fit test for each case and level value in dB of the signal with confidence interval of 95% were applied. The null hypotheses are listed below.

1. H_{0_A} : Data fit a Normal pdf.
2. H_{0_B} : Data fit a Weibull pdf.

3. H_{0_C} : Data fit a Rice pdf.
4. H_{0_D} : Data fit a Rayleigh pdf.

Results of those tests are shown in **Tables 1 -3**. Since the conditions of this type of test is there must be at least 5 elements in order to obtain reliable parameters, this test was applied to some level values of the signal because there were not enough information. This is the reason why not all possible values are shown.

Tables 1 – 3 shows a better fit to a Weibull and Rice pdf, for the other tests there are not enough information to confirm the fit. In order to characterize the signal, Weibull pdf was chosen as the best fit. The parameters for each level of the signal and case are shown in Tables 4 – 6.

TABLE 1 RESULTS OF GOODNESS OF FIT TEST FOR DESCENDENT CASE

Level [dB]	H_{0_A}	H_{0_B}	H_{0_C}	H_{0_D}
-44.5	0	0	0	1
-44	0	0	0	1
-43.5	0	0	0	1
-43	1	0	0	1
-42.5	0	0	0	1
-42	1	0	0	1
-41.5	1	0	0	1
-41	1	0	0	1
-40.5	1	0	0	1
-40	0	0	0	1
-39.5	0	0	0	1
-39	0	0	0	1
-38.5	0	0	0	1
-37.5	0	0	0	1
-37	0	0	0	1
-36.5	0	0	0	1
-36	1	0	0	1
-35.5	1	0	0	1
-35	1	0	0	1
-34.5	0	0	0	1

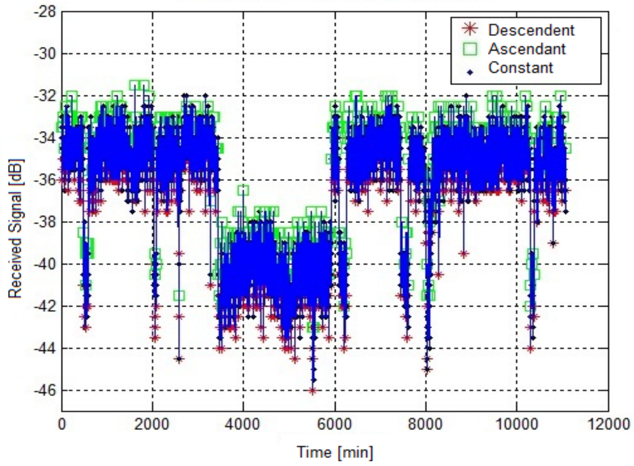

FIG. 5 CLASSIFICATION OF THE DYNAMIC OF THE MEASURED SIGNA

TABLE 2 RESULTS OF GOODNESS OF FIT TEST FOR ASCENDANT CASE

Level [dB]	H_{0_A}	H_{0_B}	H_{0_C}	H_{0_D}
-41.5	0	0	0	1
-41	0	0	0	1
-40.5	1	0	0	1
-40	0	0	0	1
-39.5	0	0	0	1
-39	0	0	0	1
-38.5	0	0	0	1
-38	1	0	0	1
-37.5	0	0	0	1
-37	0	0	0	1
-36.5	0	0	0	1
-36	1	0	0	1
-35.5	1	0	0	1
-35	1	0	0	1
-34.5	0	0	0	1
-34	0	0	0	1
-33.5	0	0	0	1
-33	0	0	0	1
-32.5	0	0	0	1
-32	0	0	0	1

TABLE 3 RESULTS OF GOODNESS OF FIT TEST FOR CONSTANT CASE

Level [dB]	H_{0_A}	H_{0_B}	H_{0_C}	H_{0_D}
-44	0	0	0	1
-43.5	0	0	0	1
-43	0	0	0	1
-42.5	0	0	0	1
-42	0	0	0	1
-41.5	0	0	0	1
-41	1	0	0	1
-40.5	0	0	0	1
-40	1	0	0	1
-39.5	1	0	0	1
-39	0	0	0	1
-38.5	0	0	0	1
-38	0	0	0	1
-37.5	0	0	0	1
-37	0	0	0	1
-36.5	0	0	0	1
-36	1	0	0	1
-35.5	1	0	0	1
-35	1	0	0	1
-34.5	1	0	0	1
-34	1	0	0	1
-33.5	1	0	0	1
-33	1	0	0	1
-32.5	0	0	0	1
-32	0	0	0	1

TABLE 4 STATISTICAL PARAMETERS FOR DESCENDENT CASE

Level [dB]	k	λ
-44.5	41.77739	46.75953
-44	41.60071	79.01272
-43.5	40.74588	66.10655
-43	40.42871	55.29717
-42.5	40.14499	79.62583
-42	39.55161	67.87356
-41.5	39.29798	99.89456
-41	38.80158	78.23872
-40.5	38.31699	90.29666
-40	37.86818	97.10892
-39.5	37.18807	56.99257
-39	36.77166	87.09323
-38.5	35.873	171.5512
-37.5	35.02695	64.17111
-37	34.68037	68.06274
-36.5	34.21202	81.78366
-36	33.88323	121.9095
-35.5	33.35662	122.1128
-35	32.93314	171.1851
-34.5	32.46527	263.8467

TABLE 5 STATISTICAL PARAMETERS FOR ASCENDANT CASE

Level [dB]	k	λ
-41.5	44.20123	122.9567
-41	43.51202	102.4882
-40.5	43.16427	61.7567
-40	42.60144	70.8082
-39.5	42.23862	65.16574
-39	41.9158	47.35953
-38.5	41.54704	56.55568
-38	41.38272	54.32599
-37.5	40.3876	79.6019
-37	40.5792	78.08219
-36.5	40.11563	63.57542
-36	38.72393	53.93092
-35.5	39.12766	23.0157
-35	38.82265	18.83783
-34.5	37.30731	31.72193
-34	36.54149	85.51059
-33.5	36.08003	72.24685
-33	35.73347	59.62865
-32.5	35.53519	47.2163
-32	35.2657	35.41361
-31.5	35.24462	83.97179

TABLE 6 STATISTICAL PARAMETERS FOR CONSTANT CASE

Level [dB]	k	λ
-44.5	44.57952	85.86382
-44	44.24518	105.5672
-43.5	43.07512	38.18975
-43	42.599	60.63251
-42.5	42.23845	48.92242
-42	41.96452	48.79378
-41.5	41.61901	49.4321
-41	41.15889	50.31377
-40.5	40.89396	51.21311
-40	40.56574	52.7448
-39.5	40.29601	55.16532
-39	39.85725	63.42838
-38.5	39.49265	69.73722
-38	38.91844	48.17599
-37.5	37.585	36.17963
-37	36.85911	43.4964
-36.5	36.11872	50.32271
-36	35.69963	44.81098
-35.5	35.49988	44.75373
-35	35.20791	45.40684
-34.5	35.05221	46.74836
-34	34.7551	55.13069
-33.5	34.50221	59.18153
-33	34.20913	82.60771
-32.5	33.86773	115.4273
-32	33.31776	106.0288

Generation of the Signal and Validation of the Model

Validation of the created statistical model includes the generation of a new signal from extracted Weibull pdf parameters for each level in dB and case. The generated signal is shown in FIG. 6. A comparison through second order statistics of the original analyzed signal and the generated one was done. Results of that comparison are shown in FIG. 7 and 8.

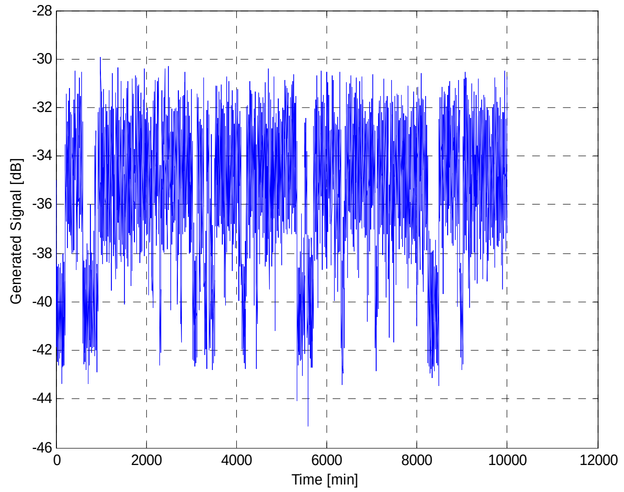

FIG. 6 GENERATED SIGNAL FROM EXTRACTED STATISTICAL PARAMETERS

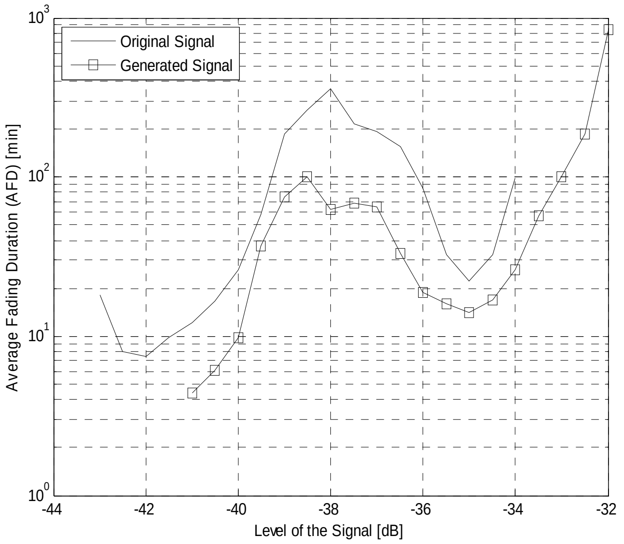

FIG. 7 COMPARISON OF AFD BETWEEN ORIGINAL AND GENERATED SIGNAL

Generated signal of FIG. 6 was created by using Weibull parameters of Tables 4 – 6 and at first sight it seems similar to the signal of FIG. 3. Second order statistics confirm this hypothesis since both curves are similar in shape and values, especially in level crossing rate of **FIG. 8** where an on-off behavior around -38 dB is appreciated which is a characteristic of urban scenarios (Scalise, 2005) as the one where measures were taken; it also confirms that the values of the measured signal concentrates in two sets: from -30 to -37 dB and from -39 to -45 dB. For the average fading duration there is a higher point in -38 dB which indicated signal remains more frequently under that level and descends for the next levels but it preserves the ascendant tendency. The values in average fading curves of the original and generated signal are not exactly the same but they have the same shape and characteristics of a typical AFD curve (Pérez Fontán, 2008). In this way it is concluded that a similar statistical signal was created from the proposed channel model.

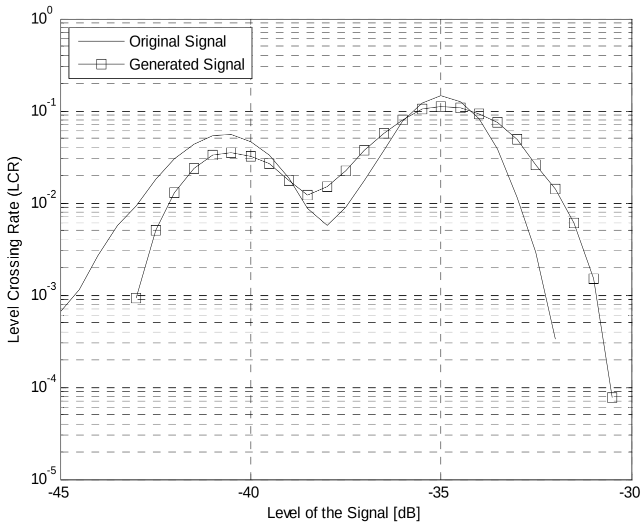

FIG. 8 COMPARISON OF LCR BETWEEN ORIGINAL AND GENERATED SIGNAL

Conclusions

A Ku-band signal was analyzed in this paper in order to create a wireless channel model. That signal was obtained from a measurement campaign done in Mexico which contains a TV signal. During the measurement campaign it was detected two different periods based on the quantity of rain. Since rain is the principal source of attenuation, samples corresponding to that period were used; the average quantity of rain was 0.0419 mm. The model was based on the analysis proposed by U.C. Fiebig in [6] where three types of movements were identified in the signal: ascendant, descendent and constant. From this classification, data were examined according to the cases and the amount of events by analyzing the current and precedent samples. After data was analyzed, the probability of each event is computed, and then a goodness of fit test is applied to determine if data (according to the case and attenuation value) fits a specific probability

density function so its parameters were computed. The parameters of the pdf according to the case and level values are the channel model itself because with these data a new time series can be generated. For the analyzed signal, data fit a Weibull pdf. The last phase of this model is validation of it which consists in the comparison of second order statistics: LCR and AFD were curves of original and generated signal were very similar concluding in this way those Weibull parameters for each case characterizes the wireless channel. The methodology presented in this paper could be used to obtain a wireless channel model of any band to analyze the behavior of the signal. The generation of a new signal is useful to simulate the behavior of the wireless channel in the design of new telecommunication systems or to analyze new fading mitigation techniques.

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